Lupins - an alternative protein source for use in shrimp feeds

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Abstract

The efficacy of lupins as an ingredient in shrimp feeds has been the focus of a number of research groups. Whole seed meals, kernel meal and protein concentrates derived from a number of different species and cultivars have been evaluated. The main areas of interest have been the digestibility of the lupin products and their effect on the digestibility of nutrients within the whole diet, and the effect on growth and feed conversion efficiency over a range of inclusion levels. Lupin kernel meal and protein concentrate appear to be more useful ingredients than the whole-seed meal. The insoluble, non-starch polysaccharides (or fibre) in lupins have an adverse effect on feed digestibility. The seed coat (or hull) is predominantly fibre. Its removal, to produce kernel meal, results in a much more digestible and useful feed ingredient. The protein and amino acids in lupin kernel meal and in the protein concentrate are well digested by shrimp, with an average apparent crude protein digestibility of >90%. Plant breeders are continually developing new cultivars of lupins that are better suited to particular soil, climatic and agronomic conditions. Recent research has focused on evaluating the new cultivars, as the results obtained in earlier studies using cultivars that are now rarely grown, may not be applicable to the lupins that are currently available on the global market.

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Introduction

There has been considerable interest in the use of lupins as a partial or total replacement for fishmeal in aquaculture feeds. The earliest reported work was with a meal derived from the whole seeds of the white lupin, *Lupinus albus* (L.) which was used in feeds for rainbow trout, *Oncorhynchus mykiss* (Walbaum), (Hughes 1988; de la Higuera, Garcia-Gallegro, Sanz, Cardenete, Suarez & Moyano 1988). Since then a considerable body of work has been published with a number of species of lupins in feeds for shrimp and fish, particularly for salmonids (reviewed by Glencross, 2001, Chien & Chiu 2003, Glencross, Boujard & Kaushik 2003a; Glencross, Curnow & Hawkins 2003b; Glencross, Evans, Jones & Hawkins 2004). Most of the early studies in Australia that addressed the suitability of lupins in feeds for shrimp, focused on the narrow-leafed lupin, *L. angustifolius* (L.) cv. Gungurru (Smith 2002). A limited amount of additional work has been carried out with the white lupin, *L. albus* (Sudaryono, Tsvetnenko & Evans 1999a; 1999b), and in South America with the Andean lupin (or pearl lupin) *L. mutabilis* (Sweet) (Molina-Poveda, Lucas & Smith 2004). However, plant breeders are continually developing new cultivars of lupins which are better suited to the different soil, climatic and agronomic conditions encountered in the growing areas. So the findings of earlier studies may no longer be valid or applicable to the mixture of new cultivars of lupins that now make up the product that is available on the global markets.

Lupin products which have been evaluated in aquaculture feeds include meals prepared from whole or dehulled seed (lupin kernel meal). In addition, a lupin protein concentrate, prepared by air classification of kernel meal from *L. angustifolius*, cv. Gungurru, has been evaluated in a number of studies (Sarac, Thaggard, Rose, Kelly & Gravel 1998; Sudaryono *et al*., 1999a,b; Carter & Hauler 2000; Booth, Allan, Francis & Parkinson 2001). More recently protein concentrates from seed meals of *L. angustifolius* and the yellow lupin *L. luteus* (L.) have been prepared using chemical extraction methods. These products have been evaluated in feeds for rainbow trout (Glencross, Evans, Dods, McCafferty, Hawkins, Maas, & Sipsas 2005; Glencross, Hawkins, Evans, Rutherford, Dods, Maas, McCafferty & Sipsas 2006a). A consistent finding with all of the fish and shrimp species studied so far is that lupin kernel meal is a much more digestible and useful feed ingredient than the whole seed meal (reviewed by Glencross, 2001). Moreover, the kernel meal is likely to be more economical for use than the protein concentrates, particularly in shrimp feeds.

Research into the use of lupin meals in shrimp feeds has focused on determining the digestibility of kernel meals, the effect that inclusion level of lupins has on growth response, and identifying the factors that may limit the use of lupins in the feed. In this paper, we review the recent research into the use of lupins in shrimp feeds and report on the digestibility and performance of a kernel meal derived from a cultivar of *L. angustifolius*, Kalya, which is typical of the mixed product from Australian bulk grain wholesalers that is currently available on the global market. In addition, we discuss the effect of lupin non-starch polysaccharides and alkaloids on the digestibility and performance of the feeds when tested with the black tiger shrimp, *Penaeus monodon* (Fabricius).

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Chemical composition

Unless otherwise stated, all compositional data are expressed on an ‘as used’ basis. Typically, lupin seeds have a crude protein (CP) content of between 31 and 42%, which is higher than the content of most other grain legumes. However, there is considerable variation in protein content among species and cultivars and even within cultivars. The highest protein content of all lupin species is found in *L. mutabilis* which has between 38 and 50% CP in the whole, unprocessed seed but when processed to remove the oil and seed coat, the kernel meal can contain > 65% CP. Of the commercial species of lupins, *L. luteus* is generally considered to have the highest protein content of whole seed (37 to 41%, while the kernel typically contains about 53% (Table1, Petterson, Sipsas & Mackintosh 1997; Sipsas, 2003). The whole seed of *L. albus* is also high in protein, having a protein content of between 30 and 40%, and the kernel having about 42%. The protein content of *L. angustifolius* seed from both old and new varieties typically ranges from 27 to 38%, with the kernel having about 41%. In comparison, dehulled, solvent-extracted soybean meal has a crude protein content of about 48%. The crude protein content of fishmeal is highly variable, but high quality Peruvian fishmeal provides a widely-accepted yardstick with about 67% protein.

The amino acid composition of lupin protein is similar to that of soybean but is characterised by relatively high levels of arginine, 11.3 to 12.2 g/16 g N, which is about twice the level in soybean protein. However, it has relatively low levels of methionine, 0.65 g/16 g N, or about half that of soybean protein. Though the cysteine content of lupin protein is relatively high (1.5 g/16 g N) and similar to that of soybean protein, the total sulphur amino acid content (methionine + cysteine) is still relatively low (2.1 g/16g N).

The lipid content of lupins also varies considerably among species and cultivars. Whole seed of *L. mutabilis* has the highest lipid content among the lupins (up to 20%). Of the commercial species, *L. luteus* generally has the lowest lipid content, from to 5.7 to 6.8 % (Table 1) and *L. albus* the highest, 8.3 to 14.5% (Petterson *et al.* 1997; Petterson 2000). The lipid in lupins comprises predominantly triacylglycerides (71.1%) and phospholipids (14.9%), with lesser amounts of free sterols (5.2%), glycolipids (3.5%) and other lipid material (5.3%) (van Barneveld 1999; Petterson 2000). The crude fat content is significantly higher than in solvent extracted soybean meal (Table 1)

Table 1. Gross chemical composition (%) of whole seed and kernel of two species of lupins (from Sipsas 2003) and Peruvian fishmeal and solvent extracted soybean mea[1]

Species	*L. angustifolius*		*L. luteus*		Fishmeal	Soybean
	Seed	Kernel	Seed	Kernel		(solvent)
Moisture	9	12	9	12	9	9
Seed coat	24	–	27	–	–	–
Protein	32	41	38	52	67	48
Fat	6	7	5	7	11	2
Ash	3	3	3	4	13	5
Lignin	1	1	1	1	–	–
Polysaccharides	22	28	8	10	–	23
Oligosaccharides	4	6	9	12	–	12
NFE*	51	36	43	30	–	35

* Nitrogen free extractives = Seed coat + lignin + polysaccharides + oligosaccharides

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The fatty acid composition of the lipid in lupins is typical of that of most legumes and not unlike that of the residual lipid in soybean meal. It is high in mono-unsaturated fatty acids (MUFA) and poly-unsaturated fatty acids (PUFA), mainly linoleic acid and linolenic acid, but with none of the nutritionally-important, long-chain omega-3 fatty acids found in marine oils (Table 2).

Table 2. Fatty acid profile of lupin lipids, soybean oil and Peruvian fishmeal lipids (expressed as % of total fatty acids). SFA = saturated fatty acids; MUFA = monounsaturated fatty acids

Fatty acid	Lupin	Soybean	Fishmeal
14:0	0.25	0.10	7.37
14:1n-5	0.00	0.00	0.05
16:0	12.82	16.31	20.98
16:1n-7	0.13	0.21	8.08
18:0	7.04	4.36	5.22
18:1n-9	31.68	11.71	5.49
18:1n-7	1.20	1.55	3.55
18:2n-6	39.01	55.70	1.32
18:3n-3	4.42	8.44	0.55
18:4n-3	0.00	0.00	1.52
20:0	0.81	0.22	0.89
20:1n-11	0.00	0.03	0.14
20:1n-9	0.32	0.14	0.43
20:4n-6	0.00	0.09	2.58
20:4n-3	0.00	0.00	0.58
20:5n-3	0.00	0.00	15.96
22:0	1.60	0.42	0.21
22:1n-11	0.00	0.05	0.22
22:1n-9	0.00	0.11	0.19
22:1n-7	0.13	0.07	0.15
24:0	0.36	0.24	0.36
22:6n-3	0.00	0.00	17.42
24:1n-9	0.00	0.00	1.02
Sum of SFA	23.1	21.9	36.9
Sum of MUFA	33.5	13.9	19.6
Sum n-3 (C=18)	4.4	8.4	2.1
Sum n-6 (C=18)	39.0	55.8	1.3
Sum n-3 (C>18)	0.0	0.0	36.4
Sum n-6 (C>18)	0.0	0.0	3.8

The carbohydrate composition of lupins is quite different from that of most legumes. It contains high levels of non-starch polysaccharides (NSP) (> 50% whole seed) and very low levels of starch (van Barneveld 1999, Petterson 2000). The NSP can be categorised as two fractions – a soluble and an insoluble fraction. In both whole seed and kernel meal, insoluble NSP (comprising cellulose, hemicellulose and lignin) predominates with lesser proportions of soluble NSP and free sugars. The seed coat is comprised mainly of insoluble NSP, and so the kernel meal has markedly less total NSP than whole seed meal. Nevertheless, the kernel meal typically contains about 40% NSP, but can contain up to 50% NSP. The NSP has a negative effect on digestibility in fish and shrimp, the magnitude of this effect is strongly influenced by the total amount of NSP in the feed. The soluble NSP in lupins are predominantly oligosaccharides and at high concentrations, could be considered anti-nutritional factors in some aquatic species.

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Though a range of anti-nutritional factors have been reported to be present in the seeds of commercial lupin cultivars, the concentrations are generally so low that they are not considered to be a limitation on the use of lupins as a feed ingredient (Petterson 1997, van Barneveld 1999). However, *L. mutabilis* and *L. luteus* cv. Teo are recognised as having high levels of alkaloids which impart a bitter taste to the seeds and which require pre-treatment to make the seed acceptable as a stock-feed or for human consumption (Glencross Hawkins, Evans, Rutherford, McCafferty, Dods, Jones, Sweetingham, Morton, Harris & Sipsas 2006b).

Digestibility

The apparent digestibility of lupin seed meal and lupin kernel meal (*L. angustifolius* cv. Gungurru) was determined by Smith, Tabrett & Moore (1998) in a study with 10 to 15 g shrimp (*Penaeus monodon*). The lupin seed meal had a significantly lower digestibility than kernel meal. The apparent dry matter digestibility (ADMD) of seed meal was 39% while that of the kernel meal was 73%; the apparent crude protein digestibility (ACPD) was 88% and 95%; respectively, and apparent digestibility of energy (ADE) was 45% and 74%, respectively. From the digestibility data alone, the kernel meal appears to be a much better ingredient than the whole seed meal for use in shrimp feeds.

In another study, Smith (2002) compared the digestibility of a series of diets containing a lupin protein concentrate (prepared by air classification) with a series containing kernel meal (*L. angustifolius* cv. Gungurru). The kernel meal was included at 200, 400 and 600 g/kg of feed, while the protein concentrate was included at 143, 286 and 429 g/kg, providing the same amount of protein as the kernel meal at each inclusion level. The lupin products were included in the feed formulations at the expense of fishmeal and wheat flour which were adjusted to balance the formulation and maintain constant the protein content. This study confirmed the high digestibility of crude protein in lupin kernel meal. However, the ADMD and ACPD of feeds containing protein-equivalent inclusions of protein concentrate were significantly greater than that of the feeds containing kernel meal (Table 3). This highlights the need to assess whether a feed containing lupin protein concentrate would be more cost effective than one containing lupin kernel meal: whether the enhanced digestibility would offset the additional cost involved in making the lupin protein concentrate.

Table 3. Apparent dry matter digestibility (ADMD) and apparent crude protein digestibility (ACPD) of shrimp diets containing incremental amounts of lupin kernel meal, and lupin protein concentrate from *L. angustifolius*, included in the basal diet at the expense of fishmeal and wheat flour (from Smith 2002)

Inclusion level (%)	Kernel meal diet		Protein concentrate diet	
	ADMD (%)	ACPD (%)	ADMD (%)	ACPD (%)
0	68	82	68	82
20	69	84	68	82
40	62	85	70	86
60	60	86	74	90

The response of juvenile *Litopenaeus vannamei* (Perez Farfante & Kensley) to diets in which fishmeal was incrementally replaced with kernel meal from *L. mutabilis* kernel meal was studied by Molina-Poveda et al. (2004). In that study the crude protein and lipid content of the diets were maintained at 35% and 11%, respectively, as 0, 25, 50, 75 and 100% of the dietary fishmeal was replaced with the lupin kernel meal. The kernel meal had been pre-treated to reduce the level of alkaloids and fat. All diets contained 10% squid meal as a source of attractants. The ADMD of the diets decreased significantly with increasing replacement of fishmeal, and in contrast to the findings of Smith (2002), the dietary protein also showed a slight decrease in digestibility (Table 4).

In a recent study, we have determined the ADMD, ACPD and ADE of kernel meal produced from a number of varieties of lupins currently under cultivation in Western Australia (Table 5) (Smith, Tabrett, Glencross, Irvin & Barclay 2006a). Though the ACPDs were similar to that found in the original study with Gungurru (range 93 to 97%, cf. 95%), the ADMDs were about 10% lower (57 to 66% cf. 73%, respectively). A sample of Gungurru was included in the aforementioned study, though it was not from the same source as in the original study. The ADMD of the Gungurru was the highest of the kernel meals in the recent study but was 7% less that that of the original Gungurru. The reason for the difference is not apparent but could be due to a location or seasonal effect.

Table 4. Apparent digestibility of dry matter (ADMD) and crude protein (ACPD) of diets for *Litopenaeus vannamei* with different levels of replacement of fishmeal with de-fatted and alkaloid-extracted kernel meal from the Andean lupin, *L. mutabilis* (from Molina-Poveda et al. 2004)

Percent replacement	ADMD (%)	ACPD (%)
0	78 ± 2.9	80 ± 3.0
25	73 ± 1.7	78 ± 1.6
50	68 ± 1.8	75 ± 2.5
75	66 ± 1.9	77 ± 1.6
100	67 ± 6.9	76 ± 3.2

In the same study, the apparent digestibility of the amino acids of the new cultivars was also determined. The individual amino acid digestibilities were generally similar to the protein digestibility, though the digestibility of methionine and cysteine was lower and more variable than for the other amino acids (Table 5). Whether this was an analytical problem or a characteristic of the digestibility of the sulphur amino acids has not been established.

Table 5. Average apparent digestibility (AD) of kernel meal from six cultivars of lupil representing 80% of production of narrow leaf lupins, *L. angustifolius*, in Australia

Nutrient	AD (%)	Nutrient	AD (%)
Dry matter	63 ± 1.8	Energy	75 ± 1.5
Crude protein	94 ± 0.4		
Arginine	98 ± 0.4	Lysine	92 ± 0.7
Cysteine	86 ± 2.3	Methionine	91 ± 2.1
Histidine	94 ± 1.1	Phenylalanine	95 ± 0.4
Isoleucine	94 ± 0.7	Threonine	90 ± 0.8
Leucine	94 ± 0.4	Valine	92 ± 0.7

No correlation has been found between the ADMD, ACPD and the chemical composition of the kernel meals (crude protein, crude fibre, total dietary fibre, insoluble dietary fibre, soluble dietary fibre). Further analyses of the NSP component are underway so that we can examine if there is a correlation between digestibility and either acid detergent fibre and neutral detergent fibre. A key outcome of this work would be to find a component of the kernel meal that correlates well with the apparent digestibility. This information could be used in deciding the most desirable characteristics of cultivars for use in aquaculture feeds or to assign better estimates of AD for lupin kernel meal samples of unknown cultivar or mixtures of cultivars.

Growth response studies

The growth response of shrimp given feeds containing various species and cultivars of lupins has been the subject of a number of studies. Sudaryono *et al*. (1999a) found the growth rate of juvenile *P. monodon* fed a diet containing 35% of *L. albus* kernel meal was significantly less than that of shrimp fed near-equivalent diets containing *L. angustifolius* kernel meal (unidentified cultivar) or solvent extracted soybean meal. The authors attributed this difference to differences in feed intake. Sudaryono et al. (1999b) also compared soybean meal with *L. albus* meal in a growth response experiment. The kernel meal was used to incrementally replace solvent extracted soybean meal in a series of feeds containing close to 40% crude protein (dry matter basis). The feeds contained fishmeal, squid meal and shrimp meal, which together comprised 36% of the feed while the soybean meal comprised 30% of the basal feed. Their data showed a progressive decrease in growth rate with increasing replacement of the soybean meal. That study demonstrated that the *L. albus* kernel meal from the unidentified cultivar was nutritionally inferior to the soybean meal. Smith (2002) found that growth rate of shrimp was not affected by the inclusion of *L. angustifolius* cv. Gungurru kernel meal in feeds at levels up to 200 g/kg. However, at inclusion levels >200 g/kg the growth rate decreased with increasing kernel meal content of the feed.

Recent studies with the new cultivars of *L. angustifolius* currently being grown in Western Australia have indicated that these cultivars perform better than the Gungurru used in the studies a decade ago (Smith, Tabrett, Glencross, Irvin & Barclay 2006b). In one study, the performance of a ‘typical’ lupin kernel meal was compared with that of solvent extracted soybean meal.

Table 6. Ingredient (% as used) and nutrient composition of diets for *P. monodon,* in which varying amounts of fishmeal have been replaced with lupin kernel meal (LKM) and solvent-extracted soybean meal (SBM)

Ingredient (as used)	Base diet	25% LKM	43% LKM	19% SBM	33% SBM
Fishmeal (68% CP)	39	25	15	25	15
Gluten (76% CP)	5	5	5	5	5
Krill meal (59% CP)	10	10	10	10	10
LKM (38% CP)	-	25	43	-	-
SMB (44% CP)	-	-	-	19	33
Flour, wheat (11% CP)	20	20	20	20	20
Starch	21	11	4	15	11
Other ingredients*	5	4	3	6	6
Composition (% or MJ kg^{-1} as used)					
Dry matter	90.6	90.3	90.0	90.0	89.5
Gross Energy (MJ/kg)	18.7	18.3	18.1	18.3	18.0
Crude protein	38.5	38.4	38.3	38..2	38.0
Digestible protein	34.0	34.2	34.4	33.8	33.7
Total lipid	6.8	6.8	7.0	6.8	6.7
Ash	7.8	6.4	5.3	6.8	6.1
Arginine	2.29	2.82	3.21	2.33	2.37
Lysine	2.52	2.23	2.02	2.33	2.19
Methionine	1.03	0.80	0.64	0.84	0.72
Threonine	1.54	1.45	1.41	1.47	1.43
Methionine + cysteine	1.45	1.27	1.14	1.32	1.24

- (%, as used): cholesterol, 0.1; lecithin (70%), 1.0; aquabind, 3.0; carophyll Pink, 0.05; L-ascorbyl-2-polyphosphate (Stay C), 0.1; vitamin premix, 0.2; fish oil content varied with diet. Solvent extracted soybean meal.

The experiment compared the performance of *P. monodon* fed diets containing the same amount of protein, but with ~22% and ~38% of the dietary protein provided by soybean meal and by the lupin kernel meal (Table 6). The lupin kernel meal, from the cultivar, Kalya, had a protein content of 37.5%, as used, which is typical of bulk lupin kernel meal samples. Shrimp of mean initial weight of 3 g were stocked with 5 shrimp per tank in an array of 120 L tanks. The tanks were supplied with filtered, heated seawater maintained at between 28 and 29º C and flowing through the tanks at about 600 mL min^{-1}. The experiment was run for 50 d following a 7-day acclimation period. The shrimp were fed the allocated diet twice daily, early in the morning and just before the lights were turned off at 5:00 pm.

The growth of the shrimp was at an acceptable rate and survival over the 50 d was >85%. There were no significant differences in the growth rates among the treatments containing soybean meal or lupin kernel meal, irrespective of the inclusion level. The replacement of fishmeal in the basal diet with soybean meal and with lupin kernel meal did not have an adverse effect on performance. In fact, with the diet containing 25% Kalya, the growth rate was significantly greater than for the basal diet (Figure 1).

The low level of methionine, or methionine + cystine, in the lupin protein did not appear to limit the nutritional value of the feed when the dietary lupin inclusion level was at 25% or 43% (Figure 1) (Smith et al. 2006b). The basal diet contained 1.03% methionine (Table 6), which is above the recommended amount of methionine (~0.92%) for a feed with this protein content (Akiyama, Dominy & Lawrence 1992). However, the growth rate of the shrimp was greater when the lupin kernel meal contributed about 22% of the dietary protein (LKM 25) and was as good as that obtained with the basal diet when the kernel meal contributed about 38% of the dietary protein (LKM 43) in the diet (Figure 1). At these inclusion levels the dietary methionine content was 0.80 and 0.64%, respectively, which is markedly less than the recommended level. From this result, it appears that the currently recommended dietary methionine specification is much higher than the requirement when the diets contain 40% crude protein. This is clearly an issue that needs to be resolved.

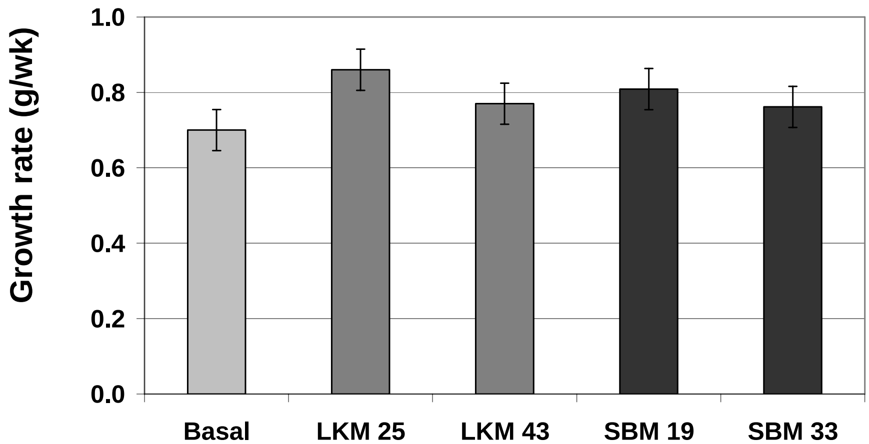

Figure 1. Growth rate of *Penaeus monodon* fed isonitrogenous and isolipidic diets in which fishmeal was replaced with varying amounts of lupin kernel meal (LKM), from *L. angustifolius* cv. Kalya and solvent-extracted soybean meal (SBM). Inclusion levels are indicated in the diet label eg LKM 25 = 25% lupin kernel meal.

In a study with *L. vannamei*, Molina-Poveda et al. (2004) found a significant decrease in weight gain and feed ingestion rate when the dietary fishmeal was replaced with the de-fatted and alkaloid-extracted kernel meal (Table 7). At 50% replacement of fishmeal, about one third of the total dietary protein was from the lupin kernel meal, *L. mutabilis*. This is in contrast to with the findings of Smith et al. (2006b) who found no decrease in growth rate when kernel meal from *L. angustifolius* supplied 37% of the protein in the diet for *P. monodon.*

Table 7. Weigh gain (%) and feed ingestion rate (FIR) of *Litopenaeus vannamei* fed diets with different levels of replacement of fishmeal with de-fatted and alkaloid extracted kernel meal from the Andean lupin, *L. mutabilis.* (From Molina-Poveda et al. 2004)

Percent replacement of fishmeal	Weight gain (%)	FIR (% biomass)
0	746 ± 84	7.8 ± 1.2
25	463 ± 89	4.9 ± 0.8
50	449 ± 27	4.5 ± 0.7
75	325 ± 60	3.4 ± 0.6
100	295 ± 39	3.5 ± 0.6

Despite the fact that the diets contained 10% squid meal as a source of additional protein and attractants, feed ingestion rate appeared to decrease progressively with increasing inclusion of kernel meal in the diet (Table 7). These data suggests that this particular type of lupin kernel meal contained some repellent compounds that resulted in the decrease in feed intake. Further studies would be useful to investigate this response in more detail and to confirm the presence of the repellent compounds. If confirmed, research to determine how these compounds can be removed during pre-treatment of the kernel meal, or countered with additional attractants in the diet would be warranted.

The effect of insoluble NSP from lupins on the growth response and feed intake was determined in a study with *P. monodon* (Smith 2002). Insoluble NSP was isolated from lupin kernel meal and added in incremental amounts to a series of diets, replacing starch in the formulation. The digestibility of the diets decreased with increasing amount of NSP. However, the insoluble NSP did not affect the growth rate of the shrimp. The shrimp appeared to compensate for the reduced digestibility of the feed by increasing their feed intake.

There appears to be no published information on the response of shrimp to the other anti-nutritional factors such as alkaloids, saponins and tannins, which are generally present at low concentrations in varieties of lupins grown in Australia. In South America, kernel meal prepared from *L. mutabilis*, contains high levels of the alkaloid, lupanin, and is treated to reduce the concentration from 3% to 0.05% before being used in shrimp feeds (pers. comm. C. Molina-Poveda, information supplied by Ecuadorian Institute for Agriculture). A recent study with *P. monodon* demonstrated that the lupin alkaloid, gramine, at concentrations from 0 to 900 mg kg^{-1} of feed, did not have a significant effect on growth rate, apparent feed intake, survival or digestive gland histology (CSIRO, Australia, unpublished data). However, with rainbow trout, feed was refused when the same alkaloid was present at a dietary concentration of 1000 mg kg^{-1}; a concentration of 500 mg kg^{-1} reduced intake by 58% compared to a diet containing 100 mg kg^{-1} of gramine (Glencross et al. 2006b).

Conclusions

As lupin meals are included in prawn feeds primarily as a protein source, high protein content and low levels of NSP are favourable characteristics of the kernel meal. However, though a lupin protein concentrate with a protein content >50% (as used) would appear attractive, the cost of making this product may result in it being too expensive to include in shrimp feed formulations. In assessing lupin products, it is important to compare their cost in terms of the cost per unit weight of protein. The low methionine content of lupin protein does not appear to adversely affect the performance of *P. monodon* when the kernel meal protein contributes less than 40% of the protein in diets that have 40% of crude protein. Recent studies indicate that the recommended specification for methionine in diets for shrimp could be reduced by one third without affecting shrimp performance.

Though insoluble NSP in lupin kernel meal does not affect the growth of shrimp, it does reduce protein digestibility. Hence, processing that reduces the NSP content of the meal will not only result in an increase the protein concentration of the meal, but it will also improve the overall efficacy of the product. However, the added cost of the processing may nullify the benefit of higher protein content and thus have a significant bearing on the usage of the product. Soluble

NSP, particularly oligosaccharides, could have an adverse effect on digestibility. However, the response of shrimp to these compounds has not been adequately studied.

Alkaloids are recognised as being anti-nutritional factors that are present in lupins but the varieties of lupins currently being grown in Australia only contain very low levels of alkaloids. However, *L. mutabilis*, grown in South America does have high levels of alkaloids. These alkaloids readily leach from the lupin meal when the meal is soaked in water (C. Molina-Poveda, pers. com). Recent work has demonstrated that alkaloids at concentrations of up to about 900 mg kg^{-1} in the feed do not appear to affect feed intake of *P. monodon*. This response may be due to leaching of the alkaloid prior to consumption of the feed by the shrimp.

From the perspectives of cost, protein content and digestibility, lupin kernel meal appears to be the most appropriate lupin product for use in shrimp feeds. It is essential that any factor or factors that limit the utilization of lupin kernel meals in shrimp feeds be identified; whether it is a methionine limitation, oligosaccharides affecting digestibility or some other anti-nutritional factor. The potential benefit of new cultivars or processing techniques that increase protein and reduce NSP contents of the kernel meal must be balanced against the cost of the product. The cost of the protein in these products must be compared against the cost of the protein in alternative protein sources and solvent extracted soybean meal, in particular.

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